EVALUATION OF DYNAMIC CHARACTERISTICS OF BASE ISOLATED RESIDENTIAL BUILDING

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ABSTRACT :

The aim of this research is an isolation story displacement evaluation of base isolated residential building according to earthquake records selection method. To analyze the seismic behavior, 15-story building which has beneficial effect of base isolation system is designed. Non-linear time history analysis is done with variables such as earthquake ground motion records. From this research, ground motion records are proposed by using a specified soil site conditions and calibration of peak ground acceleration. The time history results of base isolation buildings may be induced difference results according to each ground motion records. Therefore the detailed guidelines for the ground motion records selection method must be prepared. In the evaluation of isolation story displacement, which has been applied by proposed earthquake records, show good seismic performance and have seismic resisting safety.

KEYWORDS: base isolation building, isolation story displacement, earthquake records

1. INTRODUCTION

Base isolation, as one of the seismic design methods, isolates the ground and the building to install shear deformation devices between the building and the ground. This ground isolation technique can be applied effectively to newly built buildings, and existing buildings not to make the seismic design or to be short of the seismic performance. Recently, for 30 years many isolators have developed through experiments and research in Japan, America and New Zealand. Design criteria and guidelines were made for the application of these devices. Table 1 shows base isolation building lists in Korea. Based as isolation design criteria ASCE 7-05, the aim of this research is to propose earthquake records selection method and to compare response characteristics from using earthquake records.

Table 1 Base isolation building lists in Korea

Building name	Construction year	Design code	Isolation type	Isolation Device (Production Country)
Traum Haus (13 story)	2002	AIJ, 1997	Basement isolation	LRB, Sliding bearing (Japan)
Seosan welfare center (2 story)	2005	AIJ, 2001	Basement isolation	RB, Isolation bearing,BSL (Korea,Japan)
Unison office building(6 story)	2007	ASCE 7-02, 2001	Basement isolation	LRB, RB (Korea)
Kimpo apartment (14 story)	2008	ASCE 7-02, 2001	Middle- story isolation	LRB, RB (Korea)

2. DESIGN PROCEDURE OF BASE ISOLATION BUILDING

2.1. Design of base isolation building

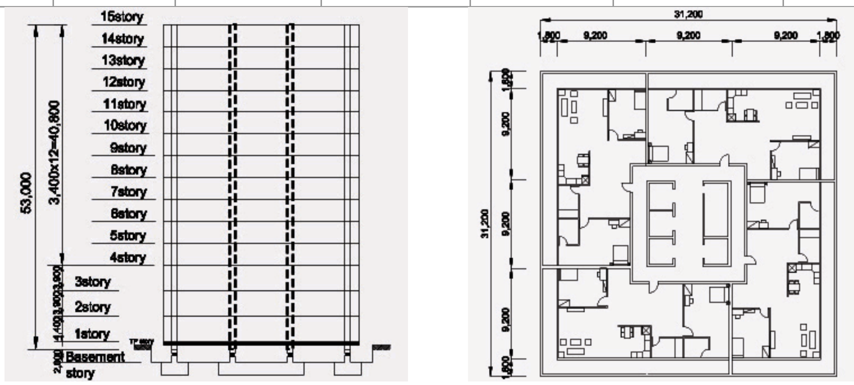
The performance evaluation of the isolation building can be to evaluate safe conditions of the isolator which could be damaged by time history analysis using earthquake records. Up to now, in Korea, there are not guidelines of isolation building design and isolators. Guidelines applied in Korea are Recommendation for the design of Base Isolated Buildings (2001) in AIJ and ASEC 7-05(2005) in ASCE. Considering building structures in this research is 15-story reinforced concrete frame building located in Seoul. Soil condition is S_c. The reason why 15-story building was selected is that the effect of the earthquake is much larger than the wind and an economical design is possible. Isolator was installed underneath transfer plate in the first floor. Yield strength of the used reinforcing bars is f_y = 400N/mm^2. Table 2 shows thickness and compressive strength of main members. Isolation analysis made the use of MIDAS Gen which was developed in Korea, and applied response modification factor 5. The used codes in design are as follows.

• Korean Building Code-Structural, Architectural Institute of Korea, 2005.4
• Minimum Design Loads for Buildings and Other Structures(ASCE 7-05), ASCE, 2005
• Building Code Requirements for Structural Concrete and Commentary(ACI 318-05), ACI, 2005

Figure 1 shows the elevation and the floor plan of the example building.

Table 2 Compressive strength of main members

`	Slab		Beam	Column	Wall	
	Thk.	f'c	f_{ck}	f'c	Thk.	f'c
1F~4F	190 mm	24 N/mm^2	24 N/mm^2	35 N/mm^2	500, 250 mm	35 N/mm^2
5F~15F	190 mm	24 N/mm^2	24 N/mm^2	30 N/mm^2	500, 250 mm	30 N/mm^2



（a）Elevation (b) Plan
Figure 1 Building elevation and plan

2.2. Selection of isolator

The soil type and period as fixing foundation (not to be isolation) of the considering building are as follows.

• Soil type : S_C
• S_{DS} : 0.439 sec.
• S_{D1} : 0.234 sec.
• $T_a = 0.075 \times h^{0.75}$ = 1.417 sec (h = building height, 50.3m)

Isolation period about DBE (design based earthquake) level can be evaluated by the Eqn. 2.1, but in advance effective stiffness of the isolator should be known. Therefore it is convenient to calculate the target isolation period and displacement, on the assumption that isolation is 3.5 second (empirical assumption), as gradually applying isolation displacement.

$$T_D = 2\pi\sqrt{\frac{W}{k_{D_{\min}} g}} \tag{2.1}$$

$$D_D = \frac{gS_{D1}T_D}{4\pi^2 B_D} \tag{2.2}$$

Where, g = acceleration of gravity
S_{D1} = design 5 percent damped spectral acceleration parameters at 1 second period
T_D = effective period of seismically isolated structure, at the design displacement in the direction under consideration
B_D = numerical coefficient related to the effective damping of the isolation system at the design displacement

After the Eqn. 2.1 and 2.2 were applied repeatedly, needed isolation devices stiffness could be calculated as follows.

- In case of 3.5 second in building period

$$k = \frac{4\pi^2 W}{gT^2} = \frac{4\times128048\times3.14^2}{9.8\times3.5^2} = 42066kN/m \tag{2.3}$$

Table 3 Isolator specification

	Specificaton	RB	LRB1	LRB2
`	Shear modulus	0.39 N/mm²	0.39 N/mm²	0.39 N/mm²
Member size	Outer diameter	1100 mm	900 mm	1400 mm
	Lead bar diameter	-	210 mm	240 mm
	Rubber thk.	7 mm	5.8 mm	7 mm
	No. of rubber layer	29	34	29
	Total rubber thk.	203 mm	197.2 mm	203 mm
	1st shape factor	36.8	38.8	50.0
	2nd shape factor	5.4	4.6	6.9
	Steel plate thk.	4.3 mm	4.3 mm	4.3 mm
	Product height	419.4 mm	425.1 mm	523.4
Axial capacity	Axial stiffness	5308×10^3kN/m	4128×10^3kN/m	11258×10^3kN/m
	Surface pressure	15 N/mm²	12 N/mm²	15 N/mm²
Horizontal capacity	Lateral stiffness	1.803×10^3kN/m	-	-
	1st stiffness	-	16.66×10^3kN/m	38.68×10^3kN/m
	2nd stiffness	-	1.282×10^3kN/m	2.976×10^3kN/m
	Yielding load	-	276.1 kN	360.6 kN
	Effective stiffness	-	2.68×10^3kN/m	4.75×10^3kN/m
	Damping ratio	-	30.2	22.6

Table 3 shows the isolator specification selected by lateral stiffness with above procedure. Where, RB means rubber bearing layer by the rubber and steel plate. LRB means lead rubber bearing contained the lead bar in the middle core of layer rubber. It can be calculated that isolation displacement and period about DBE (design based earthquake) level and MCE (maximum considerable earthquake) level

- $T_D = 2\pi\sqrt{\dfrac{W}{k_{D_{\min}} g}} = 2\times 3.14\sqrt{\dfrac{128048}{9.8\times 47652}} = 3.29\,\text{sec}.$
- $D_D = \dfrac{g S_{D1} T_D}{4\pi^2 B_D} = \dfrac{980\times 1.6\times 3.29}{4\times 3.14^2\times 1} = 130.74mm$
- $D_M = 1.5 D_D = 1.5\times 130.74 = 196.12mm$
- $T_M = \dfrac{D_M\times 4\pi^2 B_M}{g\times S_{M1}} = \dfrac{196.12\times 4\times 3.14^2\times 1}{980\times 1.6} = 4.93\,\text{sec}.$

Where, g = acceleration of gravity
S_{M1} = maximum considered 5 percent damped spectral acceleration parameters at 1 second period that is calculated by 1.5times to S_{D1}
T_M = effective period of seismically isolated structure, at the maximum displacement in the direction under consideration
B_M = numerical coefficient related to the effective damping of the isolation system at the maximum displacement

As the allowable maximum displacement of isolator was 197.2mm in Table 1, safety of the isolator could be certain about the maximum displacement of MCE level (D_M=196.12mm). That was, when shear deformation ratio of the isolator considered 100 %, the maximum displacement was not exceeded with a permitted limit of 197.2mm. Therefore it was certain that the isolator was proper. Figure 2 shows a layout of isolator location.

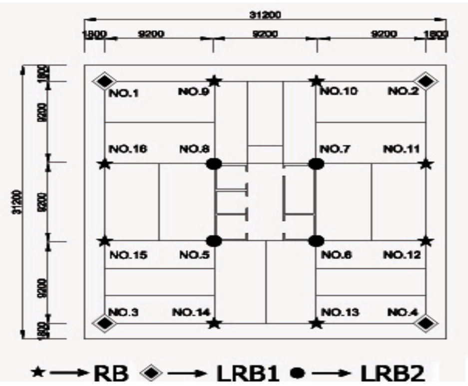


Figure 2 Layout of isolator location

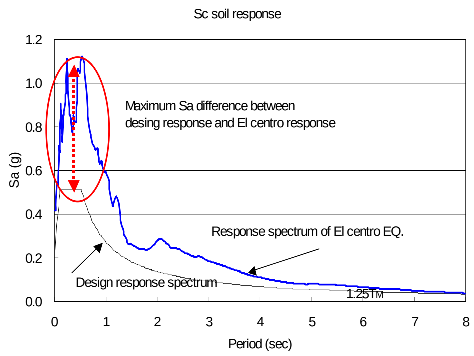


Figure 3 Response of El centro EQ.

2.3. Variables of isolation story displacement evaluation

Isolation structure analysis of 15-story building was performed that was based on a target period of 3.29 second in displacement 197.2mm, and effective stiffness 47652 kN/m of the actually applied isolator. Main analysis variables are as follows.

- Seismic Risk : DBE, MCE
- Earthquake records : Conventional records - El Centro(1940), Taft(1952), Hachinohe(1961),
  Proposed records - Loma Prieta(1989), San Fernando(1971), Cape Mendicino(1992)

3. PROPOSITION OF EARTHQUAKE RECORDS SELECTION METHOD

3.1. General

According to ASCE 7-05 which has guidelines about using the design of isolation building and the earthquake records, it describes that average SRSS response of each pair earthquake records should be scaled to be more than 1.17times of the code specified response spectrum between design period 0.5 T_D and maximum period 1.25T_M. However, it need to be careful that various response differences are made as characteristics of ground motions and soil conditions. Therefore to use systematic earthquake records, the present problem of earthquake records use can be described as follows.

- It is difficult to use earthquake records for the time history analysis of base isolation building because of the rare instrument earthquake records in Korea.
- Nevertheless using available earthquake records of America, most records are a severe earthquake records, and it is difficult to get the earthquake records consisted of pair (2 components of horizontal direction).
- The seismic response of the building is related to ground motions, as using scaling method of earthquake records, there are a few code descriptions about the soil condition between earthquake records and building location.
- Because with using earthquake records PGA (peak ground acceleration) scaling can make differences as earthquake records and soil types, it is short of consistency. When using time history analysis procedure, it needs the method selecting earthquake records with similar response characteristics in soil condition and design response spectrum. As figure 3, when reviewing El centro earthquake record used generally, because the response difference is very large between acceleration response in ground motion and design spectrum by code, it is difficult to define that real building response is proper. Also, it wonders if ground characteristics with earthquake record is considered, from now, it is necessary to study the scaling method and to select method of earthquake records.

3.2. Procedure of earthquake response selection method

In this section, the response result will be comparable of conventional and proposed in this research according to earthquake records selection method. The earthquake records were collected in CD-ROM of U.S.D.C(1996) and U.S.G.S(1992) in USA. Also soil type was classified by using SMCAT program. The example building was a 15-story apartment, and scaling factor and isolation displacement were evaluated. The considering soil type was S_c classified representatively in Korea. The other soil type was excepted, as judged from being similar respond characteristics. In order to evaluate scaling effect of earthquake records using time history analysis, the proposed earthquake records selection method in this research is evaluated through procedures from 1 to 6 as follows. List of earthquake records is table 4.

Table 4 List of earthquake records

	Event name	Date D/M/Y	Comp.	PGA	Remark
Conventional method	El Centro	18/05/40	S00E	206 cm/sec²	- Soil type do not consider - 0.11g scaling do not do
	El Centro	18/05/40	N90E	343 cm/sec²	
	Taft	21/07/52	S69E	175 cm/sec²`	
	Taft	21/07/52	N21E	153 cm/sec²	
	Hachinohe	16/05/68	EW	206 cm/sec²	
	Hachinohe	16/05/68	NS	314 cm/sec²	
Proposed method	Loma Prieta	18/10/89	EW	106 cm/sec²	- Soil type consider - 0.11g scaling do
	Loma Prieta	18/10/89	NS	69 cm/sec²	

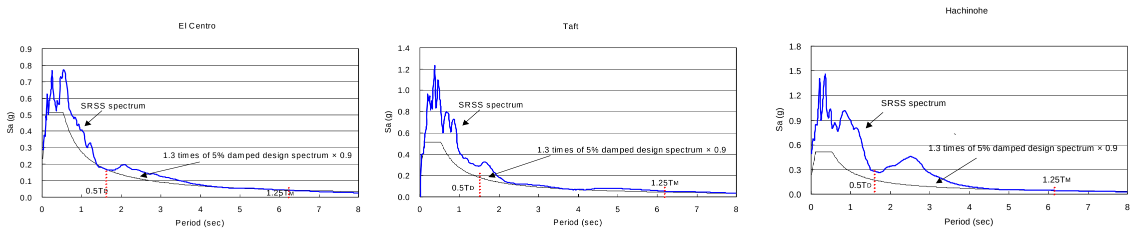
	San Fernando	09/02/71	EW	112 cm/sec²	
	San Fernando	09/02/71	NS	119 cm/sec²	
	Cape Mendicino	25/04/92	EW	112 cm/sec²	
	Cape Mendicino	25/04/92	NS	114 cm/sec²	

- Conventional earthquake records : El Centro(1940), Taft(1952), Hachinohe(1961)
- Proposed earthquake records in this research : Loma Prieta(1989), San Fernando(1971), Cape Mendicino(1992)

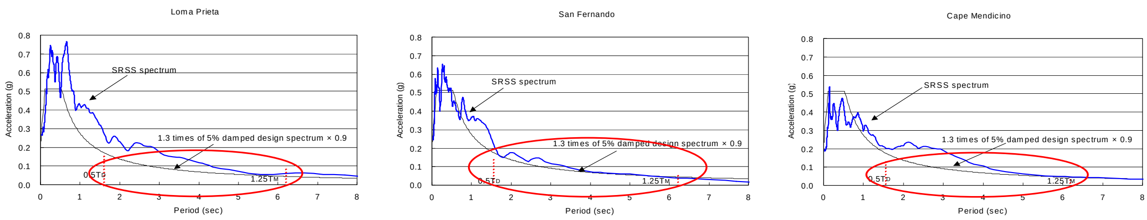
- Earthquake records selection procedures

1) Select the same described earthquake records as soil type of the building.
2) Set PGA (using 0.11g in this study) scaling of earthquake records.
3) Select response of earthquake records within mean ± standard deviation of design response spectra.
4) Perform time history analysis to use selected earthquake records.
5) Select more than 3 records in time history earthquake records with each pair, and set scaling appropriately. Scaling the horizontal earthquake records of each pair apply SRSS about 5% damped response spectrum. The mean of SRSS spectrum about period response between 0.5 T_D and 1.25 T_M sets scaling of ground motions on 0.9×1.3=1.17 times than 5% damped spectrum.
6) Response after 1.25 T_M is ignored as calculating scaling factor because of decreasing usually $1/T^2$.

From this result, Figure 4 shows scaling factor calculation method with conventional and proposed ground motions.



(a) Conventional method



(b) Proposed method

Figure 4 Scaling factor calculation

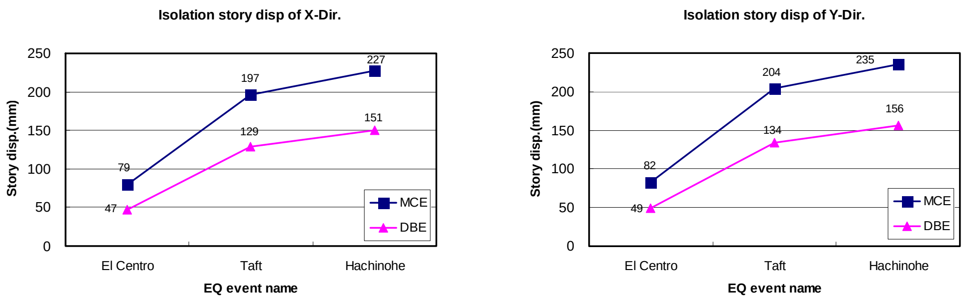
4. ISOLATED STORY DISPLACEMENT AND HISTORIC BEHAVIOR OF ISOLATOR

4.1. Scaling factor evaluation

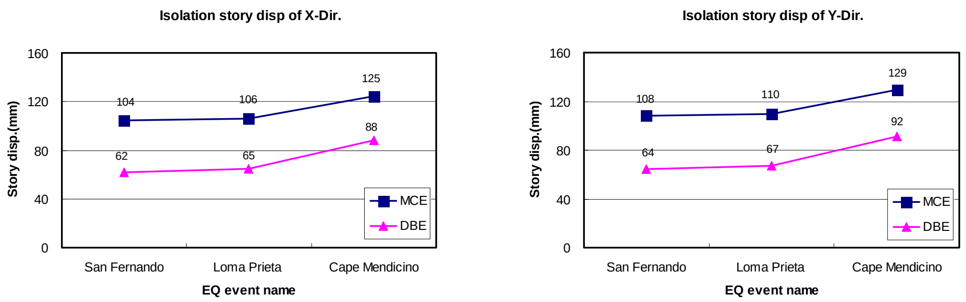
From this result, calculated scaling factor listed with isolation displacement on Table 5 and Figure 5. In KBC 2005, it is prescribed in the rules that MCE is 1.5 times in DBE. Isolation displacement of MCE level is calculated by 1.5 times scaling factor calculated on DBE level. According to table 5 and figure 5 as using earthquake records with the conventional method, it could be certain that various difference of displacement response appeared in every kind of records. Especially Hachinohe earthquake, isolation displacement on MCE level exceeds the limitation of the device as 203mm. While isolation displacement as using earthquake records with proposed method is calculated almost stably within the limitation of the isolator. Therefore it could make confirmation that earthquake records calculation method proposed in this research is most pertinent. From this, stability of base isolation building is closely dependent on characteristics of each earthquake record.

Table 5 List of earthquake records and isolation story displacement

Event name	Direction	Scaling factor		Isolation story displacement	
		DBE	MCE	DBE	MCE
El Centro	X	0.689	1.033	47.4 mm	79.1 mm
Taft	X	1.676	2.514	129.4 mm	196.7 mm
Hachinohe	X	1.287	1.930	150.5 mm	227.0 mm
El Centro	Y	0.689	1.033	49.1 mm	82.0 mm
Taft	Y	1.676	2.514	134.5 mm	204.0 mm
Hachinohe	Y	1.287	1.930	156.1 mm	235.4 mm
San Fernando	X	1.046	1.568	61.9 mm	104.4 mm
Loma Prieta	X	0.995	1.492	64.8 mm	106.0 mm
Cape Mendicino	X	0.822	1.232	88.3 mm	124.7 mm
San Fernando	Y	1.046	1.568	64.2 mm	108.2 mm
Loma Prieta	Y	0.995	1.492	67.2 mm	109.9 mm
Cape Mendicino	Y	0.822	1.232	91.6 mm	129.3 mm



(a) Conventional method



(b) Proposed method

Figure 5 Displacement of isolation story

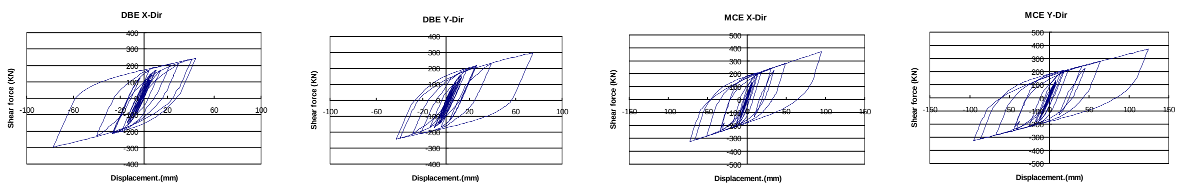
4.2. Historic behavior of isolator

Figure 6 shows the hysteretic behavior of isolator that was LRB 3(diameter 900mm) and LRB 8(diameter 1400mm) on Figure 2, with using shear force to displacement. Where Cape Mendicino earthquake record and MCE level were considered. Using earthquake records selected by proposed procedures from this research, the hysteretic behavior of isolators about shear force and displacement shows proper behavior to the limit of isolator capacity. Judging from these analyzing results, isolation devices were selected by rational procedure.

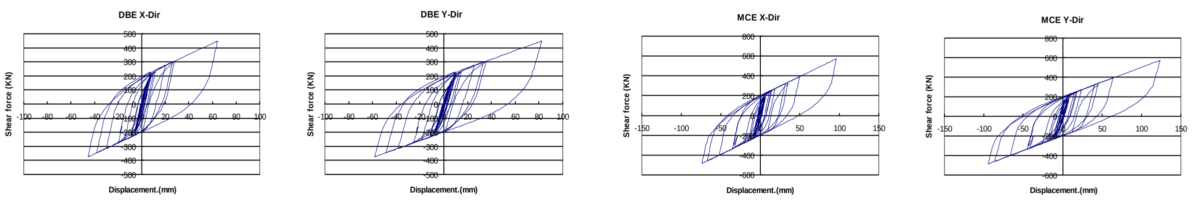
5. CONCLUSIONS

In this research, earthquake records selection method for base isolation structures was proposed by evaluating 15-story buildings. From this, main results are derived as follows.

1) It is necessary that reasonable standards or codes be established about using procedure of ground motions for time history analysis of base isolation building. This research suggests the method that can select earthquake records with soil type and PGA scaling.
2) As a result from evaluating isolation story displacement with earthquake records, isolation displacements on MCE level with conventional method were exceeded the shear displacement limitation of the isolation device. While isolation displacements with proposed method were appeared almost stably without regard to any kind of earthquake records. It was certain that the displacement of isolator could be safe within design displacement.
3) In this research, the response of isolation building about S_c soil type was evaluated. It is necessary that response evaluation of base isolation building about various soil types.



(a) Cape Mendicino earthquake response of LRB 3



(b) Cape Mendicino earthquake response of LRB 8

Figure 6 History curve of isolator

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